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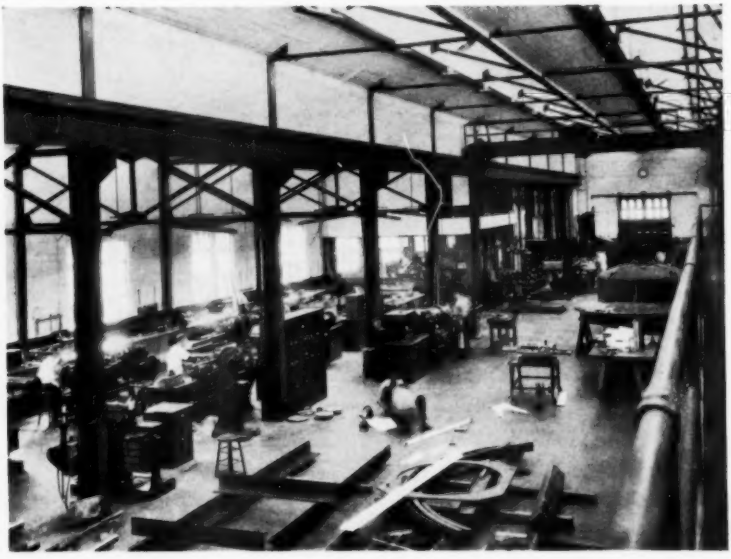
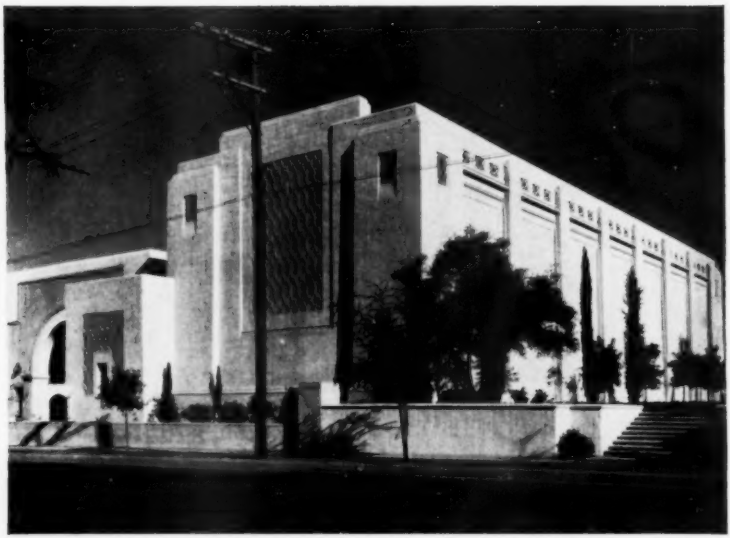
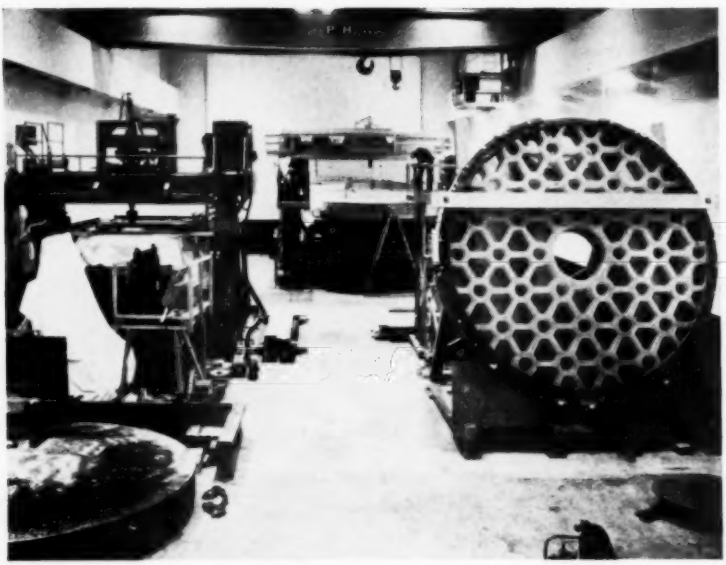


Photos.: F. Ellerman

Fig. 2.—THE MACHINE SHOP IN PASADENA.
(a) *above*, External View. (b) *below*, Interior.





Photos.: F. Ellerman

THE OPTICAL SHOP IN PASADENA

Fig. 4 (*above*) **Outer View. Fig. 5** (*below*) **Interior View from Visitors' Gallery.**

Journal of the Royal Astronomical Society of Canada, 1942.

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PLATE IX

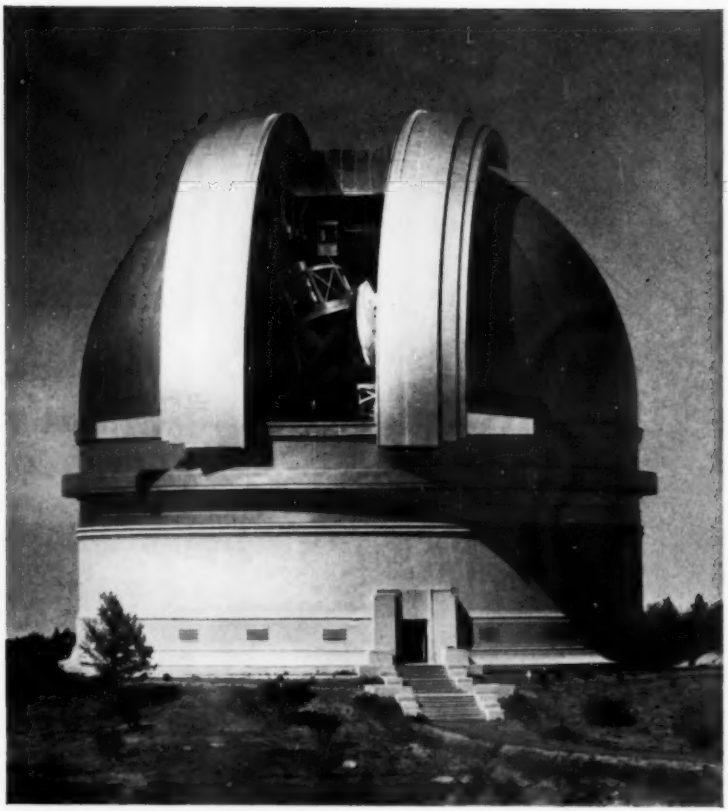

Photo.: O. K. Harter

Fig. 12.—THE 200-INCH DOME FROM E.N.E.

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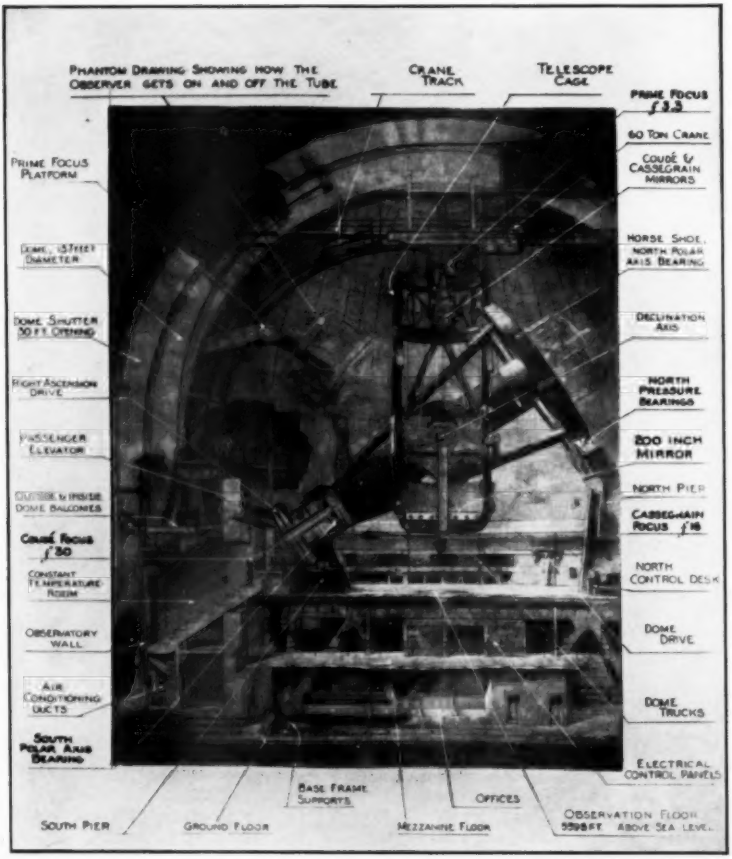

Drawing by R. W. Porter

Fig. 13.—SECTION OF 200-INCH TELESCOPE AND DOME.

This drawing shows the 200-inch Telescope, cut away along a vertical plane through the polar axis, and as it appears to you,—with explanatary notes on the margin giving essential features of the instrument. The tube weighs about 140 tons, the entire instrument 500 tons, and the rotating dome weighs 1000 tons.

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THE ASTROPHYSICAL OBSERVATORY OF THE CALIFORNIA INSTITUTE OF TECHNOLOGY

By J. A. ANDERSON
Executive Officer of the Observatory Council

(With Plates VII-X)

IT IS not likely that the above will remain the permanent designation of the observatory. No doubt another name will be chosen when, after the present war is over, the observatory can be completed and begins to contribute its bit to the work of pushing back still farther the known limits of the universe. What this name will be nobody knows. It will be chosen and announced at the proper time by the Observatory Council of the California Institute of Technology.

General plans for the observatory were outlined by the Observatory Council and its Advisory Committee in 1928-29, soon after the International Education Board of New York had agreed to support the undertaking financially. Dr. George Ellery Hale was then the Chairman of the Council, and on the Advisory Committee were many of the world's leading astronomers, engineers and scientists. According to these plans the observatory should have as its chief instrument a reflecting telescope of 200 inches aperture and in addition auxiliary telescopes and equipment necessary for the most efficient and effective use of the large instrument. The observing equipment should be on the best mountain site found within practical working distance of the home office and laboratories at Pasadena. Dr. Hale always stressed the advantage of thus separating the observing station and the offices and laboratories. It makes it possible for the astronomical staff to live comfortably and normally in a town or city and still have the

advantages of a mountain site for their telescopes. Naturally the observers have to make one trip to the observing station per month for a stay of a few days; if this trip is a very long one it will involve some loss of time, might be expensive and tiresome. Hence the two stations should be "within practical working distance" of each other. At the time the Mount Wilson Observatory was founded, when travel was by horse-drawn vehicles, 10 or 12 miles was perhaps near the upper limit of such a distance, and that was then just about the road distance between Pasadena and Mount Wilson. To-day the road distance has been increased to 30 miles or so, but thanks to motor cars and better roads it is really much shorter than it was 35 years ago. Consequently, the Council in 1928 decided to define the practical working distance as anything less than about 150 miles.

How to proceed with the construction of the new observatory had to be considered and at least partially decided by the Council with as little delay as possible following its organization. It was clear that some years would be required to produce a 200-inch mirror disk if, indeed, it could be made at all; and, of course, "no disk, no observatory". The most conservative course would be to do nothing in the way of construction until the disk was ready or, at least, until it was assured. The other extreme would be to proceed with construction as if there was no doubt whatever of the success in the manufacture of a disk. A middle course was selected. The optical work on the disk would most likely have to be done in or near Pasadena, and since this work would require special machinery and a special Optical Laboratory, much time could be saved at relatively small cost by having these facilities in readiness at about the time the casting and annealing of the disk might be completed. This indicated the advisability of building as soon as possible a machine shop suitable not only for the immediate work but, later on, also for the construction of the drive and control mechanism and other appurtenances for the 200-inch telescope as well as the smaller observing units needed for the observatory. It was also thought advisable to erect fairly soon a building to house the observatory offices and laboratories. Equipment for this building, such as measuring machines, photometers of all sorts, and miscellaneous laboratory equipment could be supplied by the

shop gradually as shop-time would permit. In the meanwhile the design of the Optical Shop could be carefully studied and be ready for construction bids as soon as work on the manufacture of the disk promised definite success.

It was, however, decided not to begin any serious study and design of the large telescope and dome, or of the other equipment for the "observing station" until a satisfactory disk was assured, for everyone agreed that mechanical work such as the construction of telescope mountings and domes could easily be accomplished during the long time required for the optical work on the mirror.

Site Investigation

It was thought desirable, however, to commence a study of sites for the observing station just as soon as a reasonably good method of estimating the quality of "seeing" could be found and carefully tested. Tests of a promising method were made during the late summer and autumn of 1928, the necessary equipment was ready next spring and throughout 1929 and 1930 more than a dozen sites in the southern half of California and in Arizona were occupied. A smaller number were studied during the following two years, and the investigation was terminated in 1934. Soon thereafter Palomar Mountain in northern San Diego County, 125 miles distant from Pasadena by road, was selected as the place where the 200-inch telescope would be erected.

The telescopes employed in the investigation were 4-inch refractors mounted as shown in the photograph reproduced in Fig. 1. The eyepiece was a 210-power compound microscope. The focal length of the 4-inch objective was 36 inches, hence the magnification had the very high value of about 750 diameters. Polaris was the only star that could conveniently be observed and its diurnal motion carried its image entirely across the field of view in a matter of 10 minutes. The mounting was very rigid and with its three steel legs each 6 inches long pushed into the ground, it was amply steady. The image of Polaris under reasonably good seeing was a fairly large diffraction disk surrounded by two rings easily visible. A cross wire in the Huyghens eyepiece was oriented parallel to the motion of the star image which was then moved slightly with the adjusting screws on the telescope mounting so that it was bisected

by the cross wire. The double amplitude of the more or less rapid oscillations of the star disk across the wire was estimated in terms of the diameter of the disk taken as unity. Of course, the amplitude

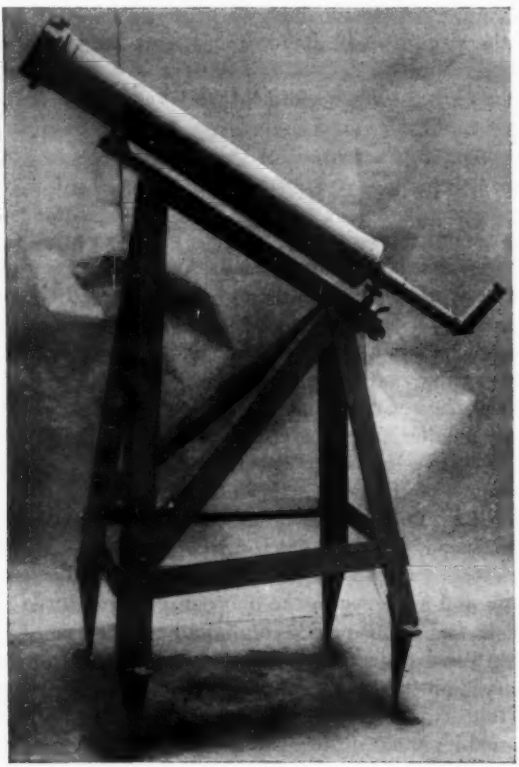

Photo.: J. Ellerman

Fig. 1.—Four-inch "Seeing" Telescope.

Focal length, 36 inches; weight about 60 pounds.

varies rapidly but with a little practice the observer has little difficulty in estimating the average value during an interval of two or three minutes. This average value was entered on the record

sheet to a tenth of a unit. Suppose the entry to be 1.0, meaning that the average oscillation during the period of observation was judged equal to the diameter of the diffraction disk or, for a 4-inch objective, 2 seconds of arc. It could then be concluded that the theshold image of Polaris made with a large telescope on a photographic plate at the same time and place would have had a diameter of two seconds.

The method was tested and calibrated on Mount Wilson. A good observer made readings with the 4-inch on enough nights to cover all the usual grades of seeing. These were compared with the estimates of seeing made by the regular observer at the 60-inch reflector, a number of readings being made each night. The results gave the following calibration:

Mount Wilson Scale	Readings with 4-inch
1	4 seconds of arc
2	2.5 to 3 " " "
3	2 " " "
4	1.4 " " "
5	1.0 " " "

A number of star plates made at the 80-ft. Cassegrain focus of the 60-inch covering several years, and upon which the seeing was recorded, were selected, and on these the fainter images were measured. The results agreed very satisfactorily with the above calibration.

The investigation showed that, over the area covered, all sites had essentially the same seeing provided they were not adversely affected by obvious local disturbing conditions. Such local effects may be quite large as was shown in the early summer of 1929, when five observers were stationed on Mount Wilson for about two weeks. Their stations covered only the region immediately surrounding the observatory, but it was clear that on a slope, or especially in one of the small canyons to the west of the 100-inch dome, seeing was always about two units lower on the scale than it was on top of the ridges. Later on, similar tests were made on Palomar Mountain by the writer and one of the regular observers with similar results.

The arrival over Southern California of a barometric low was generally heralded by poor seeing at all stations. As the low passed

eastwards and temperatures gradually rose good seeing returned.

While the method used in this investigation proved to be satisfactory it is now fairly certain that before long a purely instrumental method of measuring seeing will be perfected which may have important applications in other sciences, particularly in Meteorology.

Construction in Pasadena

Returning now to construction work in Pasadena where the first unit was to be a machine shop. Tentative plans were presented to the Council early in 1929 but it was not until January 1930 that the final plan was submitted for bids. Construction was soon begun and in October of the same year the shop was opened and work began. A small force of six men were employed the first month; this was slowly expanded to about a dozen six months later. A view of this shop is shown in Fig. 2 (Plate VII). It is a one-story building, 50×200 feet, with a partial basement for storage and general utilities, and a partial mezzanine floor for drafting rooms.

The Astrophysical Laboratory was begun late in 1930 and was completed by the end of 1931. It is a five-story building approximately 55×128 feet, two stories above ground and a basement and two sub-basements, the latter being entirely underground. On the roof are two small domes, one of which was designed to house the cœlostat of a 26-inch reflecting solar telescope; the other one, a telescope mainly for students' use. An external view of the building is shown in Fig. 3. Some work on the solar telescope was done in the next year or two, but soon it became necessary to put it aside for more pressing matters in preparation for the arrival of the large mirror disks.

By the end of 1931 the attempt to have the large disk made of fused silica had to be given up, and the Corning Glass Works began their work of producing larger disks of Pyrex or similar high-silica, low-expansion glasses. By June 1932 they had made and sent to Pasadena a 26-inch solid disk and a ribbed-back disk 30 inches in diameter. These were intended eventually to be used in the solar telescope, but for the time being they served the experimental purpose of testing the suitability of ribbed construction for the larger mirrors, particularly, of course, the 200-inch.

Two opticians who had in the meanwhile received training at the Mount Wilson Optical Shop were given temporary facilities in three basement rooms of the Machine Shop where they made the two disks into good mirrors which were then subjected to careful tests under controlled temperature conditions. The ribbed construction was found to be quite satisfactory, and to have the great

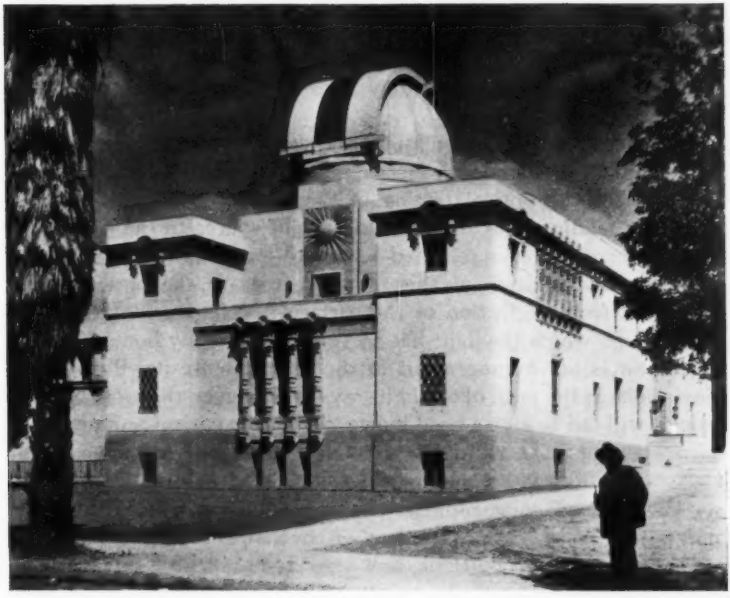

Fig. 3.—The Astrophysical Laboratory in Pasadena.

advantage of reaching temperature equilibrium after a change much more rapidly than the solid disk. When these tests had been made in Pasadena, the Corning Glass Works had already cast successfully a 60-inch ribbed disk and were preparing for the next larger size which was to be a 120-inch to serve as the testing flat for use in parabolizing the 200-inch.

Everything had gone so well and rapidly at Corning that the

Observatory Council now had no hesitation in authorizing the construction of the Optical Shop which was completed in the summer of 1933. Figs. 4 and 5 (Plate VIII) show respectively exterior and interior views of this building.

The 200-inch room shown in Fig. 5 has the inside dimensions 53×165 ft. and 39 ft. in height. Beyond the left wall of this room is a narrower two-story and basement suitably divided up into smaller optical work-rooms, the plan being that this part of the building shall become the Optical Shop of the observatory when the 200-inch telescope is completed, while the large room with its excellent temperature control may become a valuable experimental laboratory.

In the design of this building, and especially of the large room, every effort was made to insure that it should be as perfect as possible for the optical testing of large mirrors. Such tests are made by sending light from a small bright source to the surface of the mirror where it is reflected back and forms an image near the source. Examination of this image reveals to the optician any deviation from perfection of the surface tested, *provided* that the air through which the light has travelled is optically homogeneous. If the air is not homogeneous in the optical sense it will produce deviations in the path of the light rays so that even the most perfect mirror will fail to give a good image, and in the case of an imperfect mirror the optician will have great difficulty in deciding what imperfections, if any, his mirror really has.

With a small mirror, in the testing of which an air-path of only a few feet is involved, it is not often that there is any serious difficulty, unless conditions are very bad indeed; but with a mirror like the 200-inch, where the total air path is about 225 feet and the diameter of the light cone in nearly 17 feet, it is quite another matter.

The cause of optical inhomogeneity in air is, of course, variations in its index of refraction. In a pure gas the refractive index varies with temperature and pressure, and in a mixture of gases, also with the composition. Water vapour is usually the only variable constituent of air, hence the humidity must be uniform as well as the temperature and the pressure if air is to be optically homogeneous. Pressure variations are, as a rule, not present in air unless it is in

turbulent motion, consequently in the Optical Shop there remain the two physical factors temperature and humidity to be controlled, and of these temperature presents the more serious difficulties.

Unless the temperature in a room is the same as the temperature outside there will be a flow of heat through the walls of the room. As an example, consider a summer day when it is warmer outside than inside the room. The heat flows *in* through ceiling and walls, and *out* through the floor—for the ground under the building will be much colder than the outside air, and in general somewhat colder than the room. Through windows and doors heat flows faster than through walls; consequently it follows that the temperature inside the room will be quite irregular; warmer near windows and doors than near continuous walls, and cooler near the floor than elsewhere. On a cold day in winter the analysis will be somewhat different, but the result will still be irregular temperature distribution throughout the room.

Two things may be done to improve matters:

1. Heat flow may be slowed up by generous use of insulating materials in ceiling, walls and floor.

2. Irregularities in the heat flow may be avoided by omitting windows and making the doors as much like a portion of the walls as possible.

The concrete walls of the building are consequently without windows and are covered inside with a three-inch layer of cork board. The ceiling is similar except that it has a number of small square openings covered with heat-absorbing glass, above which are the 500- and 1000-watt lamps which furnish the necessary high illumination in the room. The lamp space is large and well ventilated through suitable openings to the outside air all around the building (See Fig. 4). The concrete floor slab rests upon a 2-inch layer of cork board beneath which is a 6-foot layer of sand, gravel and crushed rock.

The building has its own heating, refrigerating and air-conditioning system, so that if desired its rooms can be maintained for long periods of time at constant temperature and humidity. The air ducts were made much oversize for the purpose of keeping the difference in temperature of the room and the incoming air as low as one Fahr. degree if it should prove desirable to do so.

Optical tests on a 36-inch, 55-foot radius of curvature, spherical mirror soon after the building was completed were found to be very unsatisfactory although the uniformity of temperature was excellent. The reason was soon found to be variable humidity caused by the gradual drying of the concrete floor slab and the plastered walls. At the end of six months this difficulty disappeared and ever since the room has been found to be essentially perfect when care is taken to stop the air circulation half an hour before a test is to be made, and, of course, seeing to it that the floor is properly dry.

The photograph shown in Fig. 5 was taken from the visitors' gallery which extends across the south end of the room, with its floor some 12 feet above the floor level of the main room, hence the view is looking north. In the far right hand corner is the 200-inch machine, and half way down the left side is the 120-inch machine. These two machines were constructed in the Machine Shop together with a number of smaller ones to be used in working up the auxiliary mirrors for the telescope, as well as lenses, prisms, flats, etc., needed for testing and other special purposes. In the foreground to the left is the 200-inch grinding and polishing tool ready to receive its facing of glass blocks. At the right, opposite the 120-inch machine, is the 200-inch mirror disk and almost directly above is the 50-ton crane which can travel the full length of the room. Without such a crane it would, of course, be next to impossible to handle the large mirrors and tools.

Designing the Telescope Mounting

Late in 1933 the Council decided that the time had come for beginning a serious study of the 200-inch telescope mounting and they authorized the employment of a few engineers to undertake this work. Two types of mounting were investigated and compared, namely the open fork types like the Mount Wilson 60-inch, and the closed yoke type, sometimes called the English mounting, more or less similar to the 100-inch Hooker telescope.

About four years earlier the Council and its Advisory Committee had agreed on certain fundamental specifications for the telescope, of which the more important ones were:

1. The focal ratio of the main mirror shall be 3.33 (Focal length, 666 inches).

2. The Cassegrain combination shall have the ratio 16.

3. The Coudé combination shall have the ratio 30.

4. It must be possible for all combinations to reach all declinations from the north celestial pole to a reasonable distance above the southern horizon.

Specification No. 4 presents no difficulty with the fork type but is not satisfied with the yoke type as employed in the Hooker instrument which cannot reach the polar cap north of about +65°. In order to reach the pole with this type it is necessary to expand the north polar bearing into the form of a so-called "split-ring" or "horse-shoe" of rather large size, which introduces interesting mechanical and structural questions which would naturally require most careful study. One of these may be mentioned here:

The diameter of the north polar bearing would need to be of the order of 45 feet, and its load would be at least of the order of 200 tons. As a result the frictional force might be expected to be considerable, and since this force in pounds must be multiplied by 22.5 to obtain the torque in pound-feet, it follows that the driving torque would be quite large. If, as is usual in telescopes, this torque is applied near the south polar bearing the major part of it would have to be transmitted through the yoke which must have a length of the order of sixty feet. Undoubtedly the torsional deflection of the yoke would be considerable and the danger of torsional vibration would be great. To avoid this it was suggested that it might be possible to apply the driving torque at the north bearing, or possibly simultaneously at both bearings, neither of which was very pleasant to contemplate. Later on, fortunately, the difficulty was avoided by the adoption of the pressure oil-pad bearing, which reduced the friction and consequently the required driving torque to an absolutely negligible quantity.

The example just given was just one of the many problems confronting the engineers, and most of them had to be faced squarely and worked through, instead of being, so to speak, sidestepped by a fortunate and unexpected new application of a little-used principle.

As the study advanced it became increasingly probable that

either type of mounting could be designed in such a way as to satisfy all requirements. However, since a fully detailed design of either one would be a long and heavy task, an attempt was made to arrive at a choice by carefully weighing the advantages or disadvantages of one against those of the other. To give only one

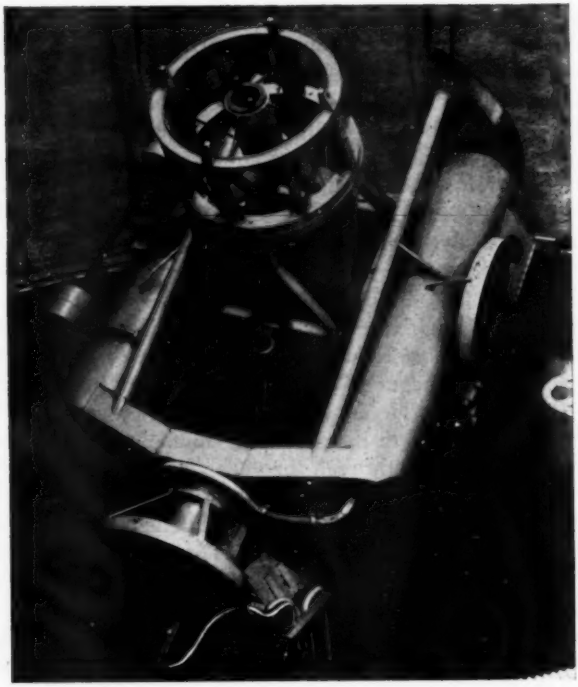

Photo.: J. Fassero

Fig. 6.—Tenth-scale Model of the 200-inch Telescope.

example: With its two supporting piers the yoke type occupies much more space on the observing floor than the fork type which leaves the entire north half of the floor free. Against this can be placed the apparently valid conclusion that for equal rigidity the fork type would weigh considerably more, and therefore its cost

would no doubt be higher. After a full discussion the Council and its Advisory Committee decided in favour of the yoke type of mounting, and also that, if possible, provision should be made for observation directly at the prime focus without the use of a Newtonian flat.

In the late fall of 1934, after the 120-inch disk had arrived in Pasadena, the engineering and drafting force was considerably

Fig. 7.—New Highway up Palomar Mountain.
Middle Section of North Polar Bearing on Trailer.

increased and the real work of designing and detailing the yoke mounting started in full earnest. A design of the tube which should prevent angular deflection of its ends under normal gravity deflection had already been found in the preliminary studies, and one important design problem now was a yoke which should be able to maintain the declination axis exactly perpendicular to the polar axis in all positions in spite of deflections due to gravity loading.

Both of these designs were tested by making the 1/10 scale model shown in Fig. 6 and subjecting the tube and yoke separately to deflecting forces of varying magnitudes and measuring angular and "skewing" deflections by optical means of ample sensitivity. These tests revealed that the tube design was entirely satisfactory, but that some changes were required in the structure of the yoke.

Late in 1935 the Westinghouse Electrical and Manufacturing Company of Philadelphia was authorized by the Council to proceed with the construction of the heavy parts of the telescope mounting and they sent two of their engineers to Pasadena to assist in the

Photo.: O. K. Harter

Fig. 8.—Scale Model of Observatory on Palomar Mountain.
The strings, except one in foreground, show paved roads. The exception is part of a fence surrounding the grounds.

design. One of these engineers spent several months in Pasadena helping in the re-design of the yoke.

Construction work at the South Philadelphia Works began in 1936 and was completed in August 1938. The mounting was shipped by water to San Diego and hauled to Palomar Mountain by truck and trailer, arriving there by the end of November 1938.

Construction at Palomar Mountain

Work was begun in September 1935. By early spring 1936 there was built a modern dwelling with garage; a suitable water supply had been developed in a nearby canyon, pumping machinery

installed there and pipe connections made to water storage facilities on a little hill on the site. These consisted of a million-gallon storage reservoir and a 50,000-gallon elevated tank to deliver water to the site for the telescope on a ridge 1000 to 1500 feet distant.

Storage tanks for fuel oil and gasoline had been installed on the little hill and water lines had been run to some distance in all directions for fire fighting, and to supply future buildings. The site for the 200-inch telescope had been cleared and made ready for excavations for the supporting piers, etc. The winter of 1935-36

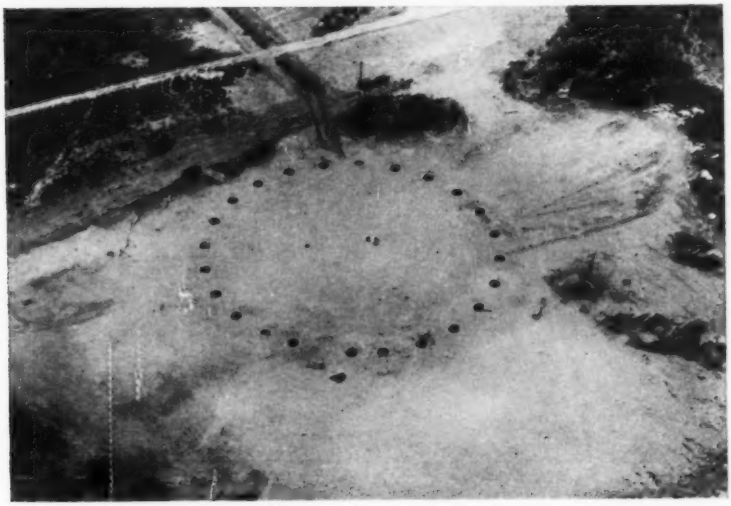

Fig. 9.—Site for 200-inch Dome, after clearing.

had been an open one with very little in the way of bad weather to interrupt work.

San Diego County had started work on a good road up the mountain, but this would not be ready for a year or more. Hence all the materials for the dwelling, water tanks, etc., were hauled up over the old roads of which there were two, both rather narrow and steep in places with sharp turns and, of course, unpaved. During 1936 something like 5000 tons of heavy structural steel for

the telescope base frame and for the stationary part of the large dome was brought up the mountain over these old roads. It should be added that the telescope mounting as well as the material for the rotating part of the big dome were hauled over the new paved highway after it was finished in the latter part of 1937 (See Fig. 7).

At the end of 1938 construction work was practically completed and Fig. 8 reproduces a photograph of a scale model of the site as seen from the east at that time.

The chief building on Palomar is, of course, the 200-inch dome.

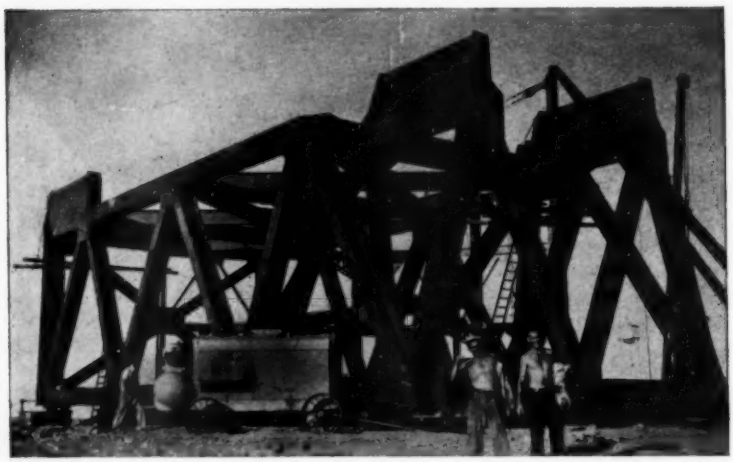

Fig. 10.—Structural Steel Base Frame to support the 200-inch Telescope.

Its diameter and height are each 137 feet. Fig. 9, reproduced from an air view, shows the site of the dome after the 24 excavations for the supporting concrete piers had been dug. Each one is about 6 feet in diameter and 6 to 8 feet deep in partially decomposed granite. Inside the circle formed by these, four larger excavations were dug to a depth of 20 to 25 feet for the piers to support the telescope base frame. These were made much deeper than the 24 excavations in order to prevent as far as possible the transmission of vibrations from the dome to the telescope. Fig. 10

shows the telescope base frame erected on these four piers, viewed from the southwest. The frame is approximately 36 feet wide, 85 feet long and 28 feet high and reaches just up to the observing floor of the dome. Two upward projections at either end will project through the observing floor and carry the two supports for the polar axis of the telescope.

Fig. 11 shows the steel framework of the stationary part of the dome building. The view is from the west. The structure shown

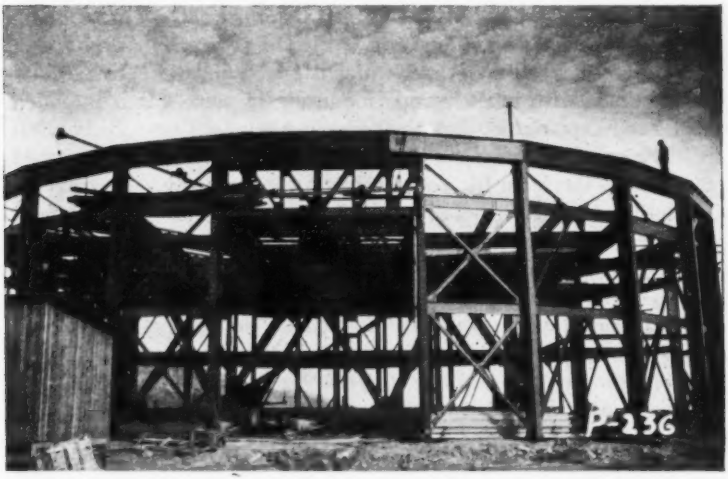

FIG. 11.—STEEL FRAMEWORK FOR STATIONARY PART OF 200-INCH DOME.
Base Frame of Fig. 10 may be seen inside.

in Fig. 10 is well-nigh lost in the maze of structural members shown here, but a part of it may be seen through the large opening in the middle foreground. This opening outlines the drive-in entrance to the dome. The continuous girder resting on the 24 vertical steel columns carries the rails on which the rotating dome trucks will roll. The girder some 8 or 10 feet below the rails marks the level of the observing floor, and another one farther down shows the level of a mezzanine floor. Relatively thin reinforced concrete walls inclose this structural steel wall, leaving an air space of some 4 feet between

them. Near the ground level the outside wall has a large number of concrete grilles for the admission of air to this space which, together with a similar space between the double wall of the rotating dome, forms a thermo-siphon, openings in the top of the dome serving as the exit for the rising air. (See Fig. 12 where the intake grilles are shown.) On a clear summer day this air circulation is quite vigorous and no doubt prevents the outside steel shell of the dome from heating up much above air temperature.

Fig. 12 (Plate IX) reproduces a recent photograph of the dome as seen from the east-north-east. Through the open shutter may be seen a part of the telescope mounting. Fig. 13 (Plate X) reproduces a drawing by Russell W. Porter which is a modified diametral section of the dome with the telescope mounting in place. It is intended to be self-explanatory but the following remarks may be helpful:

The crane shown near the top of the dome has a capacity of 60 tons on the main lift and 5 tons on the auxiliary. Its travel is from the centre line radially outwards a distance of about 40 feet.

The dome drive consists of two pairs of 5-horsepower motors, each motor driving a small standard truck wheel with solid rubber tire held by spring pressure against the inner edge of the large curved I-beam girder which rests on the 32 dome trucks. The two pairs of drives are 180 degrees apart and the spring pressure applied is sufficient to start and stop the dome without any slipping, and when the motors are locked to prevent rotation of the dome in high wind or storm.

The shell of the dome is 3/8-in. curved steel plates butt-welded over a relatively light steel rib framework on the inner face of which framework the insulation panels are supported. These panels, which may be seen in the background of Fig. 13, are each a 4-inch deep sheet-metal box, about 7 feet long and 4 feet wide near the observing floor, diminishing to about 2 feet near the top of the dome. Each box is filled with 12 sheets of 0.00045-inch bright aluminum foil said to be equivalent to 24 inches of cork board in insulating value. Any box may be taken out for repairs in case of accident, by the simple removal of four small taper wedges.

The outside and inside balconies act as a strong horizontal plate girder to maintain the lower edge of the dome accurately circular.

The diagram also indicates how the base frame (Fig. 10) of the telescope is supported. There are four supports, one at each corner. The one at the southwest corner is of the ball-and-socket kind permitting rotation only. The other three permit, in addition, both horizontal and vertical motion for adjustments of altitude and azimuth to the extent of three minutes of arc.

The mezzanine floor extends around the east and north sides of the base frame but is absent on the west side. On the east side are located the electrical switchboards, battery room, motor-generator sets and time standards, as well as comfort rooms for the public. On the observing floor along the east wall is a glass-inclosed visitors' room or gallery about 14 feet by 60 feet. Visitors enter by the entrance shown in Fig. 12 and a wide stairway leads up to the mezzanine landing, thence to the gallery on the observing floor where may be had a fine view of the telescope. A large copy of the drawing reproduced in Fig. 13 is placed there also to aid in understanding the operation of the telescope. The gallery is naturally open only in the hours of daylight.

The oil pumps and tanks for the oil-pad bearings of the telescope are on the mezzanine floor directly north of the base frame.

On the west side of the dome is the large drive-in entrance to the ground floor, mentioned above, where large trucks and trailers may enter and be unloaded by the 60-ton crane through a large removable hatch in the observing floor directly above.

In Fig. 13 will be noticed faint white lines showing the path of light within the telescope. Only two rays are drawn, and they are easily followed to the prime focus; also to the Cassegrain focus (below the 200-inch mirror cell) which they reach via a steel tube 3 feet in diameter and about 24 feet long anchored to the mirror cell. This tube incidentally performs the function of preventing direct skylight from reaching the Cassegrain focal plane, and still allowing full illumination of a field 20 inches in diameter. Its real function, however, is to support the first Coudé flat (36×53 inches) which in the diagram is shown resting on top of the 3-foot tube. Of course, when the Cassegrain focus is in use this flat is removed by a crane mounted on the north panel of the telescope tube, and is held in a secure position against this north panel.

The Coudé focus in what is labelled the "Constant temperature

room" is served in two ways. For objects south of +50° declination there are three reflections: (1) the 200-inch mirror; (2) the Coudé convex in the cage just below the prime focus; and (3) the Coudé flat which sends the light directly into the Coudé room through a slot which extends the full length of the south panel of the telescope tube.

For objects north of +50° this path is obstructed by the lower end of the telescope tube and so this obstruction is by-passed by two extra reflections clearly shown on the drawing—making 5 reflections in all. As this light path is lengthened by the by-pass, a second Coudé convex mirror is required of slightly larger diameter and somewhat different curvature.

The three convex mirrors, the Cassegrain and the two Coudés, are located in the lower cylindrical chamber carried by the cage; and when not in use are tipped up against the wall of the chamber. Each one may be tipped into position for use by remote control, the operation requiring only a few minutes. The same is the case with the larger Coudé flat—hence changing from one optical combination to another may be effected at night with no appreciable loss of time.

Telescope Drive and Control

On the main control desk (See Fig. 13) are located, among other things, two sets of 3 dials each, indicating the right ascension and declination of the point in the sky to which the axis of the telescope tube is pointing. Similar dials are located at the prime focus, and if desired may be placed also at the other observing stations. These dials are operated by selsyn motors which are connected to similar motors connected to the right ascension and declination drives respectively.

For the declination dials the problem is very simple. The declination worm moves the telescope ½ degree for each revolution, hence all that is necessary is so to arrange the selsyn motors that the dials will indicate ½ degree change for each revolution of the declination worm, and set the dials so that they read 0° 0′ 0″ when the tube points to the celestial equator.

If a similar arrangement is made for the right ascension the

indications would give the hour angle instead of right ascension, which might serve very well, but a good deal of computation may be avoided by so arranging matters that the right ascension is indicated directly, and this is easily accomplished as follows: Let the dials be driven through a simple differential and let an accurate sidereal clock* drive the dials forwards at all times. The selsyns on the right ascension worm are arranged in such a way that when the telescope turns westwards the dials turn backwards and vice versa. Thus, if the telescope is following a star the dials stand still, and indicate the coördinates of that star, since the telescope motion turns the dials backwards at the same rate as the sidereal clock moves them forwards—in reality both these motions cancel each other at the differential, leaving the dials stationary.

The drive is by a synchronous motor fed by current generated by a vibrating string Warren time standard and suitably amplified. The rate of vibration of the string, normally 60 per second, may be varied through a range of some 8 or 10 per cent. by remote control while it is running. Hence to correct for refraction, worm-gear or other known or determinable errors it is a simple matter, once the errors are known, to construct a suitable cam or other device which will vary the rate of the vibrating string, and consequently the frequency of the alternating current in such a way as to eliminate the errors.

Also it is easy by means of a second set of dials to provide automatic setting of the telescope. Let this second set be adjusted to read the coördinates of a desired new position. Set the telescope in motion in such a direction as to diminish the difference of the readings of the two sets of dials; as these readings approach equality the motion may be automatically slowed down and finally "switched over" to the normal sidereal or "tracking" drive when the two sets read the same. All of this is, of course, arranged in the electrical connections, so that the observer merely has to set up his new position on the extra set of dials, then press an "execute" button and wait until his new position comes into view. It is expected that the setting will be accurate to ± 5 seconds of arc.

*This is a second Warren time standard carefully adjusted to 60 v.p.s. and sealed up.

Since refraction will also affect the declination there is provided a declination drive, always very slow, of course.

Also, since refraction varies with temperature and pressure the amount of correction made is automatically varied by an aneroid barometer and metallic thermometer attached to the correcting mechanism.

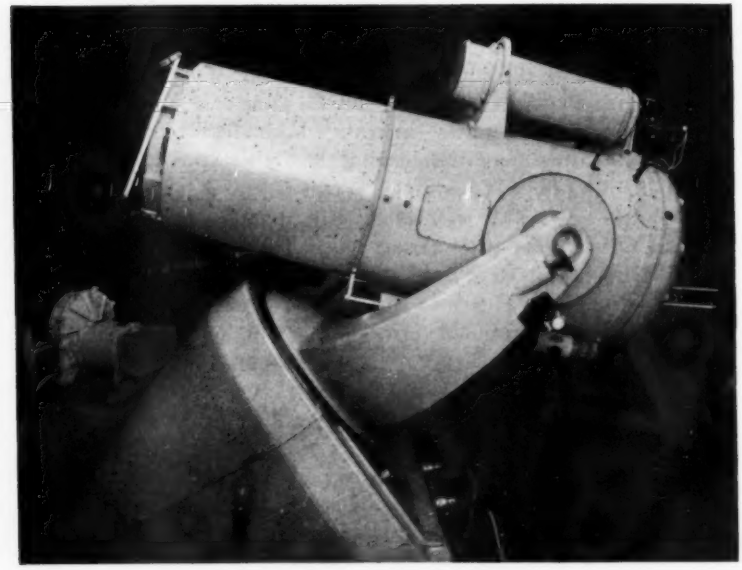

Fig. 14.—Eighteen-inch F:2 Schmidt Camera.

Progress of Optical Work

The 200-inch disk arrived in April 1936 and rough grinding was started late in May. Shaping the disk ready to be polished to a spherical surface was finished in April 1938. During this time approximately 5¼ tons of glass was removed, using up somewhat more than 10 tons of abrasives of all grades. Before polishing was begun the somewhat elaborate support system was installed connecting the mirror to its cell—the latter being the table of the 200-

inch machine. The experimental study and adjustment of the support system occupied the opticians and the author until August 1941, when parabolization of the mirror was begun.

Rough parabolization was done by alternate fine grinding and

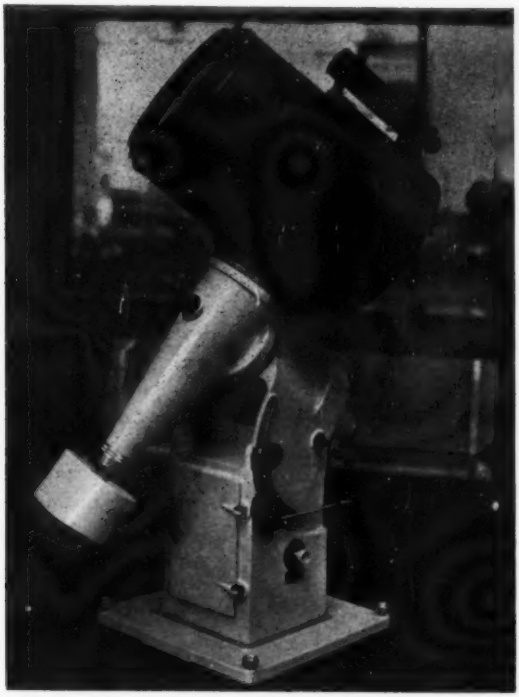

Photo.: O. K. Harter

Fig. 15.—Eight-inch F:1 Schmidt Telescope.

polishing and was completed in one month, when the final figuring was begun. This will be a slow process requiring at least a year.

The testing is done at the centre of curvature, employing monochromatic light and a special lens designed by Dr. F. E. Ross to

correct the very large spherical aberration at this image distance. The lens has a diameter of 10 inches.

The Cassegrain convex, 41 inches in diameter, is finished and the two Coudé convex mirrors, 32 and 36 inches in diameter, respectively, are nearing completion. These mirrors are tested by a modification of a method proposed by Mr. Hindle.

Auxiliary Telescopes

The invention of the Schmidt telescope became known generally about 1932. Among the first ones built in this country was the 18-inch authorized by the Observatory Council early in 1935, which was installed on Palomar in 1936 and put into operation early in September the same year. It has a spherical mirror 26 inches in diameter, 72 inches radius of curvature and hence a focal length of 36 inches. This aperture ratio of F:2 limits exposures to about 40 minutes in which time stars to the 18th magnitude are well recorded. The field covered has a diameter of 10 degrees. This instrument is already well known.

In 1938 plans were completed for a larger Schmidt of 48 inches aperture, having a 72-inch spherical mirror and an aperture ratio of F:2.5. The dome for this was completed in 1938 and the instrument itself was nearing completion in 1941, when construction work was interrupted by the war. In 1940, however, an 8-inch Schmidt of ratio F:1, having a 12-inch mirror, was completed and has been much used since.

A photograph of the 18-inch is reproduced in Fig. 14 and one of the 8-inch in Fig. 15. The guiding telescope on the 18-inch is a Cassegrain reflector of 8 inches aperture.

ON THE P CYGNI CHARACTERISTICS OF H.D. 190073 AND THE DIMENSIONS OF ITS EMITTING AND ABSORBING SHELLS

By C. S. Beals

(*Continued from page 157*)

III. The Ionized Calcium Profiles

The profiles of the *H* and *K* lines of Ca II in the spectrum of H.D. 190073 are among the most remarkable and intricate shown in any stellar spectrum. The character of these lines is illustrated by the *K* line profile of Fig. 5. As the figure shows, the principal features of this line are, first, an emission line of moderate intensity cut by a deep absorption line (subsequently designated as A1) which goes well below the level of the continuous spectrum; and secondly, a displaced double absorption line of great intensity having absorption minima at −180 km./sec. and −320 km./sec. subsequently referred to as A2 and A3, respectively. The close agreement between the profiles of the *H* and *K* lines excludes the possibility of explaining their unusual form as due to blends with other lines and the existence of these peculiar profiles must be regarded as evidence of unusual and hitherto unexplained conditions existing in the atmosphere of the star. The possibility that the absorption component in the normal position may be due to interstellar matter has been discussed by Merrill, who concludes that the absence of the corresponding line of sodium precludes this possibility. The Victoria observations are in agreement with this conclusion especially since the diffuse interstellar lines at λ4430 and λ6283 are not present in measurable strength. The point is important since the calculation of diameters later in the paper depends upon the correctness of the above conclusion concerning the stellar origin of the line.

A comparison of Fig. 5 with a microphotometer tracing published by Merrill in 1927 indicates that the line has undergone changes in detail, since in Merrill's spectrogram the violet absorption component appears the stronger of A2 and A3. Measurement of six Victoria plates on which the line appears indicates that

small changes in the displacements of the absorption components may also occur but the general character of the line remains unaltered and it appears to constitute a permanent feature of the spectrum.

The Displaced Absorption Line A2 and A3. Any theory advanced to account for this peculiar line profile must take account not only of the duplicity of the displaced absorption (A2 and A3) but also the emission in the normal position and the narrow absorption line (A1) which divides it. Taking first the double absorption

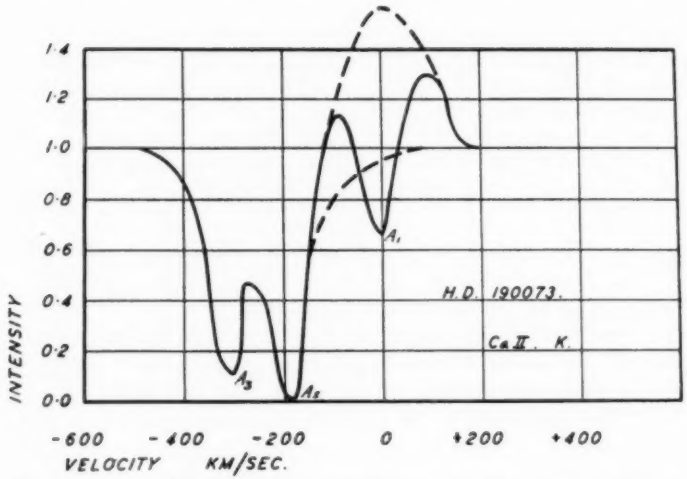

Fig. 5.—Complex Profile of Ca II *K*. Observed Profile shown by full line.

line the following suggested explanation is based on the assumption that the form of the line is largely a consequence of the distribution of velocities in the absorbing envelope. We assume that the number of atoms leaving the surface per second is a constant and that a permanent relationship exists between the average atomic velocity and the distance from the stellar surface. Let t represent the time taken by an atom to reach a given distance from the stellar surface where the velocity has the value v_t. Then since $v_t = f(t)$ we could, if we knew the form of the function, determine the length

of time Δt_v during which the atom is capable of absorbing radiation within the velocity range v_t to $v_t+\Delta v$ where $\Delta v=w$, the natural width of the line due to radiation damping and thermal and turbulent velocities. If the acceleration is variable Δt_v will vary with t and therefore, with v. But since Δt_v represents the proportion of its absorbing life during which an atom can absorb monochromatic radiation corresponding to the velocity range from v_t to $v_t+\Delta v$, then Δt_v is proportional to the number of atoms at any given moment travelling within the velocity range from v_t to $v_t+\Delta v$. Thus the optical depth τ corresponding to a particular velocity v will be given roughly by

$$\tau \propto \int_{t_v}^{t_v+\Delta t_v} E n v_t dt \qquad . \; . \; . \quad (16)$$

where E is the proportion of calcium atoms in the singly ionized state and n is the number of calcium atoms per unit volume. Let N be the number of atoms leaving the surface of the star per second. Then if the stream of atoms is in dynamical equilibrium, N will also be equal to the number reaching a given radius r per second. In a shell of unit thickness the time taken for an atom to traverse the shell will be $1/v$ and the number of atoms in the shell at a given instant t will be N/v; and n, the number of atoms per unit volume, will be

$$n=N/4\pi r^2 v_t;$$

substituting this value of n in equation (16) the expression for τ becomes

$$\tau \propto \int_{t_v}^{t_v+\Delta t_v} \frac{EN}{4\pi r^2}\, dt \qquad . \; . \; . \; . \quad (17)$$

If we assume that E is constant and that the proportional change in r during the time Δt is negligible then, to a first approximation

$$\tau \propto \Delta t/r^2 \qquad . \; . \; . \quad (18)$$

If we make the reasonable assumption that Δv is approximately constant it is clear that Δt will be inversely proportional to the mean acceleration over time Δt and the displaced portion of the K line profile may be explained in a general way as due to a relation

between v and t similar to that shown in Fig. 6. In this diagram the part of the curve from A to B (with acceleration given by the mean slope of the line) corresponds to absorption A2. The part from B to C where the acceleration is sharply increased corresponds to the maximum between the two absorption components while the portion of the curve from C and D where the acceleration reaches zero and changes sign, will correspond to the absorption component A3.*

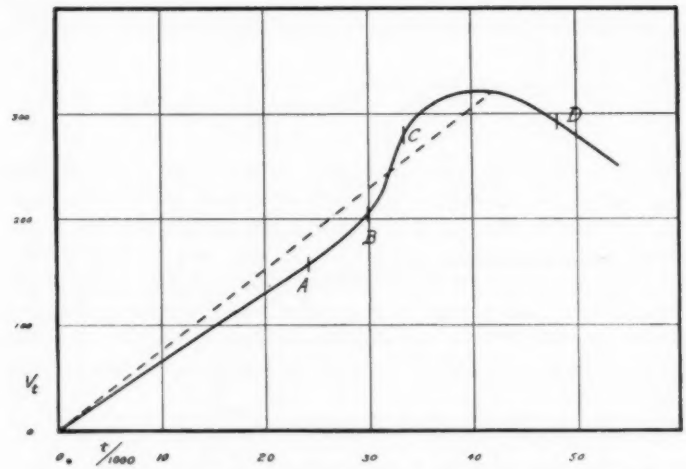

Fig. 6.—Relation between Velocity and Time for ejected atoms. The range AB is identified with A2; BC is identified with the maximum between A2 and A3. CD is identified with A3. The dotted line corresponds to uniform acceleration;

The part of the profile between zero velocity and 150 km./sec. is obscured by the presence of emission. However, apart from absorption A1, to which reference will later be made, it is unlikely that there is strong absorption in this region. This conclusion follows partly from a study of the general characteristics of the whole profile and partly from a consideration of the behaviour of displaced absorption lines in the spectra of other stars. Such

*Reasons for supposing that A3 represents the maximum velocity will be given later.

displaced absorption lines unaccompanied by emission of any strength and with the entire profile to the violet of the normal position are frequently observed in P Cygni-type spectra (e.g., lines due to Si III in P Cygni). By analogy it would appear that the dotted line of Fig. 5 would probably give a rough idea of the character of the Ca II line with the emission removed.

The absence of strong absorption in the vicinity of zero and over the portion of the v, t, curve from zero to A cannot, of course, be explained in terms of velocity distribution. Such a distribution of intensity in the line can, however, be logically interpreted as a consequence of variation of ionization with distance from the stellar surface. If, as seems probable, the vicinity of zero velocity corresponds to the level of the ordinary reversing layer, the absence of strong absorption is in accord with the behaviour of normal A0 stars where Ca II rarely appears in great strength, presumably due to the presence of ionizing radiation of sufficient strength to keep most of the calcium atoms doubly ionized. In a star such as H.D. 190073 the ejection process makes possible the formation of a screen of Ca III atoms of sufficient thickness to reduce the intensity of ionizing radiation at higher levels to a point where Ca II atoms can exist in numbers sufficient to account for A2 and A3. Stratification of this type has previously been discussed by Struve[7] and Beals[8] in connection with observations of P Cygni. Its application to the present problem makes it possible to account for the great strength of Ca II in the spectrum of H.D. 190073 on the basis of the physical characteristics of an envelope of ejected atoms without implying an excessive abundance of calcium in the star.

Before leaving the discussion of A2 and A3 it may be pointed out that the appearance of duplicity in the displaced absorption components of a P Cygni line is not unique to this star. Lines of a generally similar character associated with the Balmer series of hydrogen have been observed by Merrill[9] in the spectrum of

[7]Struve, *Astroph. Jour.*, vol. 81, p. 66, 1935.

[8]Beals, *Monthly Notices*, R.A.S., vol. 95, p. 80, 1935; also this JOURNAL, vol. 34, p. 169, 1940.

[9]*Astroph. Jour.*, vol. 69, p. 330, 1929.

H.D. 207757, by Wilson[10] in the spectrum of P Cygni and by Plaskett[11] and by McKellar[12] in the spectra of H.D. 45910 and H.D. 223385 respectively. Although such features do not in general constitute permanent features of the spectra in which they occur, it would appear that the above simple physical explanation with some modifications might well be able to account for any or all of these observations.

The Emission Line and the Absorption A1. Turning now to the emission line and the absorption A1 which divides it, the emission line may be regarded as arising in a shell of atoms surrounding the star although for the present the effective diameter of the shell is not known. The absorption line A1 in the normal position presents a somewhat more difficult problem. We wish to associate it with some particular absorbing layer whose position relative to the layers producing A2 and A3 is known. There appear to be only two possibilities. Either the line must arise in the deep reversing layer where the atom has not had a chance to acquire an appreciable velocity or it must be situated at a great distance from the star where the atom, first accelerated to a velocity of 320 km./sec., has been subsequently slowed down to a velocity approaching zero by the gravitational field of the star. Reasons have already been given for believing that strong absorption due to Ca II will not arise in the deep reversing layer but it may be profitable to follow a somewhat different line of argument relating to the observed intensity of A1.

If the line A1 arises in the deep reversing layer it must be extremely intense as well as extremely narrow. By extrapolation of the wings of the emission line as indicated by the dotted lines of Fig. 5 it appears that the unmodified emission line apart from the continuous spectrum must have a central intensity of at least 0.5 that of the continuous spectrum. Since the two parts of the line (absorption and emission) must arise in different parts of the atmosphere, the combined central intensity is obtained by the summation of ordinates. The central intensity of the observed line is 0.68 and if the effect of the emission line is removed, the

[10] *Astroph. Jour.*, vol. 84, p. 296, 1936.
[11] *Pub. Dom. Astroph. Obs.*, vol. 4, p. 18, 1927.
[12] *Pub. Am. Astron. Soc.*, vol. 9, p. 266, 1939.

central intensity of the underlying absorption line must be in the neighbourhood of 0.18. However, as the resolving power of the spectrograph used to observe the line is low, the line must be considerably deeper than it appears, so that the underlying absorption line before the emission is added to it would have to approach zero at its centre in order to produce the effect observed.

A line of such great central intensity, arising in the deep reversing layer, would almost certainly be of considerable width, with wings extending beyond the edges of the emission line and the combined profile to be expected would be very different from that of Fig. 3. It thus appears that even under the most favourable circumstances it would be difficult to explain an absorption line such as A1 as arising at such a depth in the stellar atmosphere. The only other alternative for the origin of A1 appears to be absorption by an outer layer far removed from the star. If this is the case it must be, at least in part, a self-reversal and since the absorption line in question is almost precisely in the normal position, the velocity of the absorbing atoms must be close to zero. Referring back to the previous discussion of self-reversal this would correspond to the aspect of case (*c*) on page 155 where the atom, first accelerated to a high velocity within a relatively small distance from the stellar surface, is subsequently retarded by the gravitational field of the star and reaches an approximately constant velocity at a distance which is presumably large relative to that in which the original acceleration occurred.

On the basis of this conclusion, assuming that all atoms eventually escape from the star it is possible to calculate the maximum radius at which A3 can occur.

The Dimensions of Absorbing and Emitting Shells. Since the absorption line A1 is approximately in the normal position we assume that the atomic velocity approaches zero at great distances from the star. We further assume that the force responsible for the outward acceleration drops to zero in the vicinity of maximum velocity.‡ The subsequent motion of the atom will thus be

‡Such a situation might be expected to arise if the acceleration were produced by the absorption of ionizing radiation in a screen of atoms of sufficient optical thickness. An exponential law of absorption under such circumstances would result in a relatively sharp outer boundary for the region within which accelerating radiation had appreciable intensity.

influenced by gravity alone and the maximum velocity, 320 km./sec., will correspond to the velocity of escape at some distance from the star which, may be calculated if the stellar mass and radius are known.

An estimate of the absolute magnitude and radius of the star are given in a previous publication[13] as $M=+0.7$ and $r=2.1\odot$. These values are based on the consideration that the non-appearance of interstellar lines would place the distance of the star within 280 parsecs. This limit is subject to considerable uncertainty but is probably as good as any available at the present time. On the basis of the mass-luminosity curve this would give the star a mass of 3.2 $\odot$.

From the formula for the velocity of escape we have

$$r=2G\mu/v^2$$

where r is the radius in cm., v is the parabolic velocity in cm./sec., $G=6.67\times10^{-8}$ and μ is the mass of the star in grams. For $v=320$ km./sec., $r=5.6r*$.

The radius may be similarly calculated for other velocities corresponding to distances greater than $5.6r*$. Zero velocity is theoretically at infinity but by giving the velocity of the outer absorbing layer a small positive value we may gain some idea of its probable dimensions.† Thus for $v=10$ km./sec., $r=5800r*$; and for $v=20$ km./sec., $r=1450r*$. It thus appears that the absorption A1 may take place at a distance of hundreds of stellar radii from H.D. 190073. At such distances from the star the conditions must be very similar to those in interstellar space and as a matter of fact the line A1 is indistinguishable from an interstellar line on the basis of its appearance on a low dispersion spectrogram although it has been assigned to the star for reasons already mentioned.

The above calculations of distance are based on the assumption that gravity acts alone at distances greater than $5.6r*$. If this does not hold precisely, then the qualitative argument is still valid

[13]Beals, this JOURNAL, vol. 34, p. 169, 1940.

†Since the velocity of the star is not known with certainty the observations are not able to distinguish between zero velocity for A1 and a velocity of the order of 20 to 30 km./sec.

but all the distances will be smaller by an amount which will depend on the relationship between gravity and radiation pressure or whatever other force may be responsible for the outward acceleration of the atoms. A larger mass for the star will, of course, increase the calculated radii.

The effective radius of the part of the envelope responsible for the emission line may be calculated on the basis of the following general considerations. The width of the emission line corresponds to a maximum displacement of 180 km./sec. Since this is little more than half the maximum absorption velocity exhibited by A3 it appears that the emission line must either originate entirely inside or entirely outside the radius of $5.6r*$ corresponding to absorption A3. The presence of strong absorption at A2 and A3 would suggest that the material within the radius of $5.6r*$ is also capable of emitting the Ca II lines so that it seems difficult to exclude this region as contributing strongly to the emission line intensity. If the emission line originates within the radius $5.6r*$ then a rough calculation of its radius may be made as follows. As a first approximation we assume uniform acceleration so that the average velocity is one half of 320 km./sec., the maximum.

The time taken to reach a distance corresponding to $5.6r*$ is then

$$t = 4.6r*/160,$$

and since the radius of the star is 1,460,000 km., this becomes

$$t = 4.6 \times 1{,}460{,}000 \div 160 = 42{,}000 \text{ sec. (approx.)}.$$

On this basis the v, t curve is a straight line and the time t required to attain a velocity of 180 km./sec. is readily obtained as

$$t = 42{,}000 \times 180 \div 320 = 23{,}600 \text{ sec.},$$

and the distance from the surface $d = 23{,}600 \times 90 = 2{,}124{,}000$ km. $= 2.4r*$, making the actual radius $r = 3.4r*$.

This value takes no account of the variability of the acceleration but in view of the uncertainty concerning the other calculated radii it is doubtful whether a more detailed treatment would be significant at the present time. This radius, like that for A1 and A3 may be regarded as a maximum value even though it is considerably smaller than had been expected for an emitting envelope.

It is interesting to consider this value of the radius of the emitting shell in connection with the tentative conclusion previously reached on page *xx* regarding the high degree of ionization existing in that part of the envelope corresponding to velocities of 0 to 180 km./sec. (Fig. 6.) It is clear that if the above conclusions regarding the radius of the emitting shell are correct then the emission has its origin in the highly ionized region referred to above. This is in satisfactory accord with physical theories as to the conditions necessary for emission as discussed by Zanstra[14] in connection with the nebulae and more recently by Strömgren[15] in connection with the ionization of hydrogen in interstellar space. Such a general picture of an inner ionized shell responsible for emission with the absorption lines arising outside it may have an important bearing on the interpretation of other P Cygni-type profiles although the Ca II lines are almost unique* in that they involve transitions to and from the normal state of the atom.

The interpretation of the corresponding data for the hydrogen profiles of Fig. 1 is subject to considerably greater uncertainty. The feature of the Hα profile interpreted as a self-reversal is asymmetrical in form, but there appears to be a considerable amount of absorption in the neighbourhood of the line centre. On the assumption that the most distant part of the layer producing this absorption is at zero velocity the maximum velocity corresponding to the P Cygni absorption at -244 km./sec. calculated on the same basis as for the Ca II line is $9.3r*$. In this case the extreme width of the emission line corresponds to velocity of 280 km./sec. and this suggests an effective radius for the emitting shell of the order of $10r*$. The self-reversal observed in the profile of Hγ is displaced 100 km./sec. to the violet and shows no close correspondence with that of Hα. It must be remembered, however, that the two phases do not exactly correspond and in a variable spectrum such as this it is by no means certain that either represents a state of equilibrium. This point is illustrated by the fact that

[14]Zanstra, *Pub. Dom. Astroph. Obs.*, vol. 4, p. 209, 1931.

[15]Strömgren, *Astroph. Jour.*, vol. 89, p. 526, 1939.

*The *D* lines of sodium appear faintly in emission in this star but they are unaccompanied by appreciable absorption. This may be due to the lack of sufficient neutral atoms to support an absorption line.

the time required for the atom to reach a distance of 1,000 stellar radii is of the order of a year, a length of time during which the character of the lines due to underlying layers of the atmosphere may undergo considerable changes.

It would appear probable on other grounds, however, that the value of $10r_*$ is not an underestimate of the effective radius of the emitting hydrogen shell. Apart from any features appearing in the profiles of Fig. 1 it may be pointed out that in its Be phase (Fig. 2), the hydrogen emission lines of H.D. 190073 are centrally divided by narrow minima which may reasonably be interpreted as absorption* and that their widths correspond to a velocity of about 250 km./sec. If the width of the emission lines is still due to the ejection of atoms then their maximum width corresponds to the maximum velocity of ejection which according to the above analysis occurs at a radius of the order of $10r_*$. If, as has been previously suggested, after this radius is reached the accelerating radiation is cut off or decreased, it seems probable that the radiation which excites the emission also falls to low values so that the observed emission will arise mainly at levels below $10r_*$. The application of this method of estimating the radius of emitting shells may have an interesting application in the case of certain other Be stars whose hydrogen lines resemble those of H.D. 190073, and it is proposed to begin a program of observation to study this possibility.

IV. Summary

A certain phase of the variable spectrum of H.D. 190073 is discussed and it is shown that the hydrogen line profiles can be interpreted as due to (*a*) An underlying reversing layer with physical characteristics similar to that of an ordinary A-type star giving rise to a broad winged absorption line, and (*b*) An envelope of outward moving atoms of relatively large diameter giving rise to a P Cygni-type profile which is superimposed upon the broad line.

*Struve and Schwede (*Phys. Rev.*, vol. 38, p. 1203, 1931) have interpreted some but not all double emission lines in Be stars as due to stellar rotation. In the case of H.D. 190073 lack of similarity of lines due to different elements is not in accord with the rotational hypothesis.

Certain features of the hydrogen line profiles have been interpreted as due to self-reversal in the envelope and it is shown that the most favourable conditions for self-reversal occur when the ejected atom receives a large initial impulse close to the stellar surface and is subsequently slowed down by the gravitational field to a velocity which may approach zero at great distances from the star.

The peculiar Ca II profiles are also interpreted in terms of an envelope of ejected atoms. It is demonstrated that the duplicity of the displaced absorption component can be explained as a result of an appropriate relationship between the velocity of the atom and its distance from the star.

The emission component of the Ca II profile is shown to be subject to self-reversal and reasons are advanced for believing that the corresponding absorption takes place at a distance from the star which is large relative to the radius of the shell responsible for the displaced P Cygni absorption.

From a consideration of values of the velocity of escape at different distances from the stellar surface, radii are computed for the various Ca II shells. The results indicate a radius of $5.6r_*$ for the most displaced component of the Ca II profile, $3.4r_*$ for the emission component and a radius of the order of $1000r_*$ for the self-reversal. A similar computation for the hydrogen lines leads to a value of $10r_*$ for the emission envelope. Reasons are given for believing that these represent maximum values.

Dominion Astrophysical Observatory,
Victoria, B.C.
December 22, 1941.

COMMUNICATIONS
FROM THE
DAVID DUNLAP OBSERVATORY
Number 8

A SEMIREGULAR VARIABLE IN MESSIER 4

By Helen B. Sawyer

MESSIER 4 is a cluster rich in variable stars, as forty-two are now known in it. Of these, Variable No. 4 is by far the brightest. Found many years ago by Miss Leavitt,[1] it reaches magnitude 11 or slightly brighter at maximum, about 2½ magnitudes brighter than most of the other variables in the cluster, which are ordinary cluster-type Cepheids. This variable lies on the outskirts of the cluster, though well within its boundaries, as can be seen from a print in *Harvard Circular* 366.

In 1930 periods were published by the writer[2] for 20 variables. Recently de Sitter[3] at Lembang has published a most comprehensive study of the variables. He obtained periods for all the variables in the cluster except No. 4 and No. 13, a bright star with small range. It appears important then to record all the observational material available which gives a clue to the behaviour of No. 4.

The writer has been working on this star for some years, as indicated in a footnote in Greenstein's paper[4] on the colours and magnitudes in this cluster. Seventy observations[2] of this variable were published in 1930, along with those of the 32 other variables then known, on plates taken with the Harvard 24-inch Bruce and the Mount Wilson 60-inch telescopes. These plates were taken for a study of the fainter variables so that Variable No. 4 is overexposed and the measures of it are of low weight, but indicate a long period for the star.

Since the small-scale plates at the Harvard Observatory were well suited to a study of this particular variable, some years ago the writer estimated its magnitude on all possible AM and B plates. I am much indebted to Dr. Harlow Shapley for the use of the Harvard plates. The total number of observations available from these small-scale plates is 539, of which the earliest was taken in 1889. As the

variable is frequently near the plate limit, the uncertainty in estimating may amount to several tenths of a magnitude. Since the measures were made before accurate magnitudes in the cluster were published by Greenstein, an unpublished sequence made by Miss Leavitt was used.

In 1939 Messier 4 was on the writer's observing list for two months at the Steward Observatory, and an excellent series of plates was obtained at that time with the 36-inch reflector. I am very grateful to Dr. E. F. Carpenter for the use of this instrument. The variable has been measured on 46 plates from 21 nights with the use of the following comparison stars with Greenstein's photographic magnitudes, and numbers: Gr. 544, 11.14; Gr. 313, 11.76; Gr. 362, 12.17; Gr. 512, 12.94.

Figure 1 gives a Julian day plot of most of the observations on the small-scale plates, beginning in 1893 and continuing to 1921. As can be seen from a study of the figure, apparently no definite period can be determined for this variable. The rather complete series of observations from J.D. 2416220 to 2416380 cannot be reconciled with the series from J.D. 2418360 to 2418550 on the basis of a single period. Series of plates taken throughout several successive nights about J.D. 2421010 preclude the possibility of a short period.

Figure 2 shows the observations obtained in 1939 with the Steward 36-inch reflector. Since they represent the best series available to the writer they are plotted on a scale large enough so that the times of observation may be read from the curve. The break in the series is due to full moon. Each point represents the mean of several plates on the same night, so the whole curve gives an accurate picture of the behaviour of the variable in the descending portion of its light-curve.

In Figure 1 there are not many series where the shape of the curve is definitely indicated, and where the moment of maximum can be judged accurately, so that it is difficult to determine what period is generally suited to most of the observations. Using the shape of the curve as indicated by the two good early series mentioned previously, I have determined the length of the period which appears best to fit the observations at a given date. Table I gives a date of maximum, observed or interpolated from a well-observed portion of the curve, and the apparent length of time in days from that maxi-

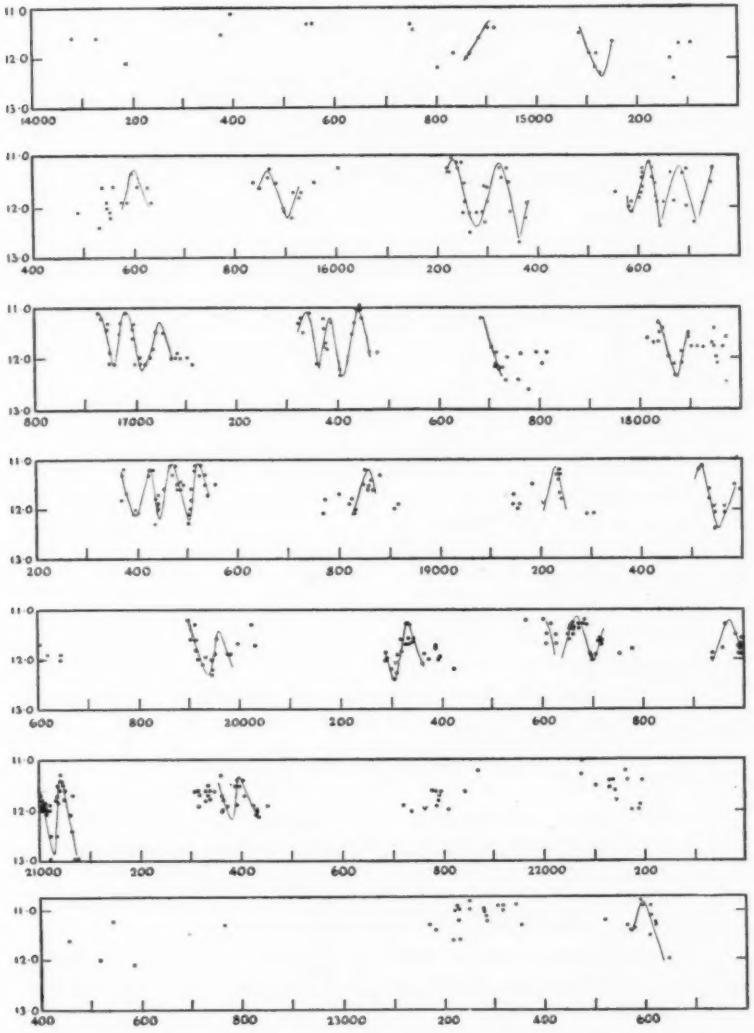

Fig. 1.—Julian day plot of observations of the semiregular variable in Messier 4.

mum to the next, and between succeeding maxima. The uncertainty in estimating the periods is about 5 days in most cases.

The usual period for the star would appear to be about 50 days. The frequency distribution of periods as estimated in Table I is as follows: 50 days, 16; 55 days, 2; 60 days, 2; 65 days, 1; 70

TABLE I

Probable Dates of Maxima and Apparent Periods for Variable 4

Maximum 2,400,000+	Periods (days)	Maximum 2,400,000+	Periods (days)
15870	50, 50, 50	18035	55, 50
16230	80, 70	18365	50, 50, 50
16615	60, 70	20330	50
16930	50, 65	20600	60, 50, 50
17335	50, 50	20970	70, 50
17680	55, 50	21300	50, 50

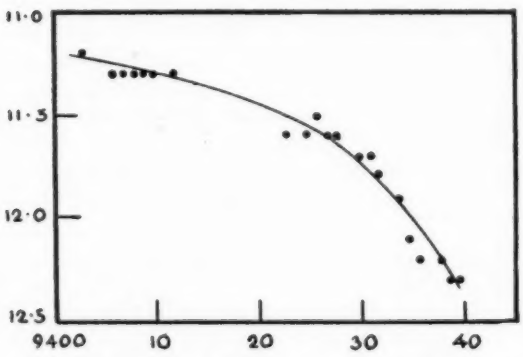

Fig. 2.—Observations of the magnitude of the semi-regular variable made at the Steward Observatory in 1939.

days, 2; 80 days, 1. In addition the period is estimated as greater than 50 days once, and greater than 70 days once.

The spectrum of such a variable is of vital interest. Fortunately a spectrum plate was available, and Miss Cannon kindly classified the star, finding it to be K2.

This might suggest that the star is an RV Tauri variable, but

the light-curves do not give the necessary confirmation of this. There is no good evidence for the alternation of shallow and deep minima, generally considered as a criterion for an RV Tauri star. Also there is more irregularity in the period. Variable No. 4 seems more to resemble the UU Herculis class of stars, created by Gerasimovic.[5] He considered that UU Herculis had two periods of 72 and 45 days which it assumed at random. The range of variation also changes and at one time the star was nearly constant in brightness. Its spectrum is G.

According to the Gaposchkins[6] however, this class of variable lacks evidence to support it. Dr. S. Gaposchkin[7] found that over an interval of seven years, UU Herculis itself behaved like an RV Tauri star. The Gaposchkins note several possible UU Herculis stars. The light-curves of Variable No. 4 bear some resemblance to one of these, Z Leonis, observed by Beyer,[8] with a semiregular period of 56.8 days. For Variable No. 4 the period of 50 days appears to hold for most of the time, but is occasionally longer, up to an increase of 50%. The range appears to vary, as well as the height or depth of maximum and minimum. As pointed out by the Gaposchkins, continuous observations of these semiregular stars over several years are necessary before one can discuss their behaviour with certainty.

It would appear impossible to say at present whether Variable No. 4 is actually a member of the cluster Messier 4. If the variable is at the distance of the cluster, its absolute magnitude at maximum is about —3. The cluster however, is situated in Scorpio in a region rich in variable stars.

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[1]Leavitt, *H.C.*, no. 90, 1904.
[2]Sawyer, *H.C.*, no. 366, 1931.
[3]de Sitter, *Natuur. Tijds. Ned. Indië*, dl. 101, afl. 2, 1941.
[4]Greenstein, *Astroph. Jour.*, v. 90, p. 387, 1939.
[5]Gerasimovic, *H.B.*, no. 857, 862, 1928.
[6]Payne-Gaposchkin and Gaposchkin, *Variable Stars*, p. 200, 1938.
[7]S. Gaposchkin, *H.B.*, no. 903, 1936.
[8]Beyer, *Astr. Abh.*, 8 C, 1930.

Richmond Hill, Ontario.
April 22, 1942.

NOTES AND QUERIES

Communications are invited, especially from amateurs. The Editor will try to secure answers to queries.

A New Centre of the Society in Quebec

As recorded in this Journal (December 1941); interest in astronomy in the city of Quebec has greatly increased recently, under the guidance of a group of enthusiastic scholars. We are now pleased to announce that the Société Astronomique de Québec has become the Quebec Centre of the Royal Astronomical Society of Canada. The city of Montreal has long boasted one of our strongest centres; we welcome the Quebec Centre as the second of our branches in this great province. A full statement of the organization of the Quebec Centre will be published in the next number of the Journal.

F. S. H.

Honour for Mr. John Patterson

The Professional Institute of the Civil Service of Canada has awarded one of its medals for 1942 to Mr. John Patterson, head of the Meteorological Service of Canada, for his long and brilliant career in scientific work and administration. The enormous expansion of aviation in recent years has imposed on our meteorologists heavy and important tasks which have been performed for Canada satisfactorily by Mr. Patterson and his capable staff. Mr. Patterson graduated B.A. in the University of Toronto in 1900 and M.A. at Cambridge University, Eng., in 1906. He joined the Canadian Meteorological Service in 1910, and succeeded Sir Frederic Stupart as its director in 1929. He is an Associate Editor of this Journal, and his many friends congratulate him on this well-deserved recognition.

C. A. C.

The Ottawa Junior Astronomical Club

An account of the year's work of the newly formed Ottawa Junior Astronomical Club is found on page 222. While the report speaks for itself, it is a great pleasure for the editors of this Journal and the members of the General Council to extend to the Ottawa Centre and

to the Junior Club heartiest congratulations on their great progress. The Dominion Astronomer, Mr. R. M. Stewart, and Mr. Thomson and Miss Burland of his staff, and Mr. Bradley and Mr. Morwick of the Ottawa Technical High School, have contributed much to the facilities, organization and guidance of the members. The young people have apparently maintained their enthusiasm throughout the year.

This Ottawa Junior Club and the Victoria Centre's annual summer classes in astronomy are among the most important and successful activities of the Society.

F. S. H.

A Very Bright Aurora, April 3, 1942

Mr. E. K. White of Ymir, B.C., lat. 49° 30′ N., long. 117° 30′ W., magnetic decl. 22½° E., reports as follows:

While at my telescope on the night of April 3 I noticed at 10.40 p.m. P.S.T. a whitish glow near the horizon in the N.E. By 10.45 a homogeneous arc had formed reaching from N.N.W. to N.E. by E. (approx.), and extending to about 20° above the flat horizon. This arc was about 5° wide, clearcut on the lower edge, and rather ill-defined on the upper, being white in colour and very bright, covering 3rd mag. stars.

At 10.50 the arc had widened and was slowly moving upward. Suddenly the centre portion, about one-third of the total length developed into a homogeneous band with a form of a huge drapery. It was by now about 10 to 15° wide, quite red on the lower edge, and greenish-yellow on the upper. The brightness was about 4th magnitude. The remaining portion of the former arc at each end of the band disappeared. Rays immediately started forming all along the horizon as far as the arc reached at its beginning. These were whitish; some long, reaching half way to the zenith, and others relatively short, all around 4th mag. Within another minute short bundles of rays were seen just above the upper edge of the curtain band, very bright yellowish-white in colour, and hiding stars of the 2nd mag. in some cases. These bundles were about 10 to 15° long and 2 to 5° wide, with irregular shapes, some lens-shaped however, all pointing pretty well to the portion of the sky between Polaris and Alpha U. Maj. (Dubhe). They would suddenly appear, increase in brightness, and then suddenly shift very rapidly, some east and some in a westerly direction, then disappear entirely, and at the same moment new ones would form and shift and disappear again, these shifts being very rapid all along the upper edge of the band. I should judge the pulsations of these rays to be about every ten seconds.

By 10.55 the curtain band was fading, and longer rays together with short ones of about 4th mag. were reaching from the horizon to nearly the zenith,

shifting slowly, fading and again brightening. These rays appeared to converge at a point near midway between Polaris and Dubhe. This would be called a corona I believe. By 11.00 p.m. only a few shorter rays were seen shifting slowly, reaching to a point about 30° above the horizon. They were fading perceptibly also. At 11.05 the display was completely over except for a faint glow in the N.E. low on the horizon, somewhat resembling dawn.

This was the most spectacular display of the aurora I have ever seen this far south, and while it appeared just after the intense sunspot display reported, I thought it might be of scientific interest. I noticed that the display was well centred on the magnetic meridian. C. A. C.

Undergraduate Mathematics at the University of Toronto

For the past five years the Mathematical Association of America has sponsored the William Lowell Putnam Mathematical Competition. In this competition the leading universities of the continent enter undergraduate teams for a six-hour examination in mathematical problems. This year the contest was won by a team from the University of Toronto. This is the third time out of the five that Toronto has won the first prize. It should also be noted that the other two years Toronto did not enter a team, as in those years the examination was set by the University of Toronto staff, as a result of their success in the previous contest. This year's Toronto team consisted of K. S. Hoyle of the third year, and of H. V. Lyons and M. A. Preston of the fourth year.

The teams from Yale, Massachusetts Institute of Technology and the College of the City of New York ranked second, third and fourth, while Cooper Union, Harvard, New York University and Swarthmore received honourable mention. The staff and students of the Department of Mathematics are to be congratulated on their maintenance of high scholastic standards as indicated by this intercollegiate competition. F. S. H.

Observations of the Lunar Eclipse on March 2, 1942

While much of the country was blanketed by clouds on the occasion of this eclipse, a number of observers in the province of Quebec were able to see the moon for at least part of the time during the eclipse. Mr. De Lisle Garneau, of the Ville-Marie Observatory, Montreal, had organized a number of observers in the province to

make naked-eye or telescopic observations of the progress of the eclipse.

At Montreal, despite clouds, Mr. Garneau and Mr. Edgar Guimont succeeded in sketching the progress of the earth's shadow across the moon's disc. At only three of the stations was it possible to estimate the colour of the eclipsed moon. At S. Bruno du Lac Saint-Jean, J. Azarius Tremblay called the colour "roussâtre" or "rouge-sang"; at Val d'Espoir (Gaspé), G. Desrochers described it as "un gris très foncé"; and at Sherbrooke, Conrad Berger called it "rougeâtre", somewhat like Betelgeuse. Other observers were able to see the eclipse at various stages, amongst clouds. It was unfortunate that a programme that was so widely planned was interrupted by clouds. However the observations received here are an evidence of a real active interest in astronomy among our members.

F. S. H.

CORRECTION TO APRIL NUMBER, PAGE 166

In the note on "The Constant of Gravitation" the last sentence (l. 5 of page) should read: The value just given is approximately equal to one 15-millionth of a dyne, and a dyne is roughly equal to one 440-thousandth of the attraction of the earth on a pound mass!"

C. A. C.

MEETINGS OF THE SOCIETY

AT OTTAWA

OTTAWA JUNIOR ASTRONOMICAL CLUB, 1941-42

A Junior Astronomical Club came into being in Ottawa as a result of a desire on the part of a group of boys who assisted in meteor observing last summer. Some of the group were new, while most of them had observed meteors at least once before. So on September 16, Donald Smellie and Franklin Cumming met in the office of Mr. M. M. Thomson at the Dominion Observatory and laid plans for the first meeting three weeks hence. Permission meanwhile had been granted by Director R. Meldrum Stewart for the group to meet at the Observatory and to use the small 4-inch equatorial if the group were officially sponsored by the Ottawa Centre of the R.A.S.C. At the next Council meeting, general and hearty approval was given any move to organize such a junior group, and Mr. Thomson was named the official representative from the Council. Actually the welfare of the group was shared by three other people, Miss Miriam S. Burland of the Observatory staff, and Messrs. B. L. Bradley and W. V. Morwick, teachers at the Ottawa Technical High School. The two teachers considered the Club an excellent extra-curricular activity for any interested boys. Strangely enough the Club has remained almost entirely a boys' group. The night that some girls did come happened to be the occasion of a rather technical talk, with the result that they did not return. Nevertheless the average attendance has been over 20, with a peak of 39, at which time the room was crowded to capacity. The general plan of meeting was intended to include instruction, some form of quiz or contest, and observation. While the first two could be pre-arranged, the last could not; our Club meeting nights were like the proverbial Sunday School picnic, almost invariably accompanied by adverse weather. A membership fee of 25c was imposed, in return for which each boy received a copy of the 1942 *Observer's Handbook*.

A summary of proceedings at the 12 meetings is as follows:

Oct. 7—Life of Percival Lowell, by Franklin Cumming.
The Planet Mars, by Donald Smellie.
Contest, to plot the stars of Ursa Major.

Oct. 21—Our Solar System, illustrated by slides and the Nixon Planetarium, by Mr. M. M. Thomson.
Contest, to plot the main stars of Cassiopeia.
General discussion in lieu of observations.

Nov. 4—Life of Gallileo, by Vernon Spence.
The Planets Jupiter and Saturn, by Lorne Gardiner.
Contest, to plot the main stars of Ursa Minor.

Nov. 18—Telescopes, by Harold Serson.
Mechanical Aids for the Astronomer, by Dave Brown.
Quiz contest by Miss M. S. Burland.

Dec. 2—How to make a Telescope Mirror, by Mr. M. M. Thomson, in lieu of Mr. A. C. Steedman.
Demonstration of Foucault knife-edge test on the Steedman 6-inch mirror.
Observation of Mars, Jupiter, Saturn, and the Moon.

Jan. 13—Election of officers, Club officially organized:
President, Lorne Gardiner; *Vice-president,* Harold Serson; *Secretary-treasurer,* Donald Smellie; *Press Reporter,* Norman Gorman.
Orion, our best Winter Constellation, by Mr. M. M. Thomson.
Quiz contest conducted by Miss M. S. Burland.
Orion Nebula, etc., through the 15-inch equatorial.

Jan. 27—Time by the Stars, i.e., using Cassiopeia, by Mr. M. M. Thomson.
Quiz contest conducted by Miss M. S. Burland.
Discussion of duration of twilight at different latitudes.

Feb. 10—Use of the Sextant in Navigation, by Mr. J. Hector.
Quiz contest conducted by Miss M. S. Burland.

Feb. 24—My Interest in Astronomy, a discussion of amateur interests—
1. Astronomical Literature, by Ken Freedy and John Donnelly.
2. A Thermocouple demonstration by Dave Brown.
3. A home-made Altazimuth device for tracking the moon, etc., by Harold Serson.
4. Observing with a 1-inch telescope, by Donald Smellie.
Quiz contest conducted by Miss M. S. Burland.

March 10—*Handbook* for March, by Lorne Gardiner.
Constellation study, Leo, by Jack Winmill and Franklin Cumming.
Quiz contest conducted by Miss M. S. Burland.

March 31—Thermocouple demonstration by Mr. H. V. Morwick.
The Moon (with lantern slides), by Donald Smellie and Mr. M. M. Thomson.
Views of the full moon through the 15-inch equatorial.

April 14—*Handbook* Study, by Harold Serson.
Nebulae (with lantern slides), by Miss M. S. Burland.
The Constellation Draco, by Donald Smellie.
Sun Dial, a summer project, by Mr. M. M. Thomson.
Adjournment for the summer months.

April 21, 1942. M. M. Thomson, *Sec'y, Ottawa Centre.*

AT OTTAWA

March 5, 1942.—The members met in the Lecture Hall of the National Museum at 8.15 p.m., with Mr. F. W. Matley, the president, in the chair. The

speaker of the evening, Flight Lieutenant F. J. Brand, addressed the group on the subject "Air Navigation."

The method of dead reckoning was described in which the pilot is assumed to know beforehand the direction and strength of wind, and the direction and variation of the compass over the route. When wind is variable, the drift can be observed against land marks or wave crests. The work of the navigator becomes more taxing when he is dependent solely on instruments for his position. Sometimes he can obtain a location by radio either by taking a bearing on a broadcast station if one is in operation, or in an emergency by contacting his base station. When the stars are visible, an astronomical position can be obtained with modern instruments and a book of tables. The horizon is given by a spirit level which is incorporated in a sextant. Then, with sights on two stars and a few minutes with the Air Almanac, a position within a mile or two can be determined.

Lieutenant Brand showed complete mastery of his subject, and drew out several questions at the close of his address.

M. M. THOMSON, *Secretary.*

March 19, 1942.—A well attended meeting of the Ottawa Centre gathered in the Lecture Hall of the National Museum to a lecture entitled "Life in the Universe", delivered by the Dominion Astronomer, Mr. R. Meldrum Stewart. Mr. F. W. Matley, the president, introduced the speaker and conducted the question period at the close of the meeting.

At the outset, Mr. Stewart mentioned that the most of what he proposed to say was contained in the book of H. Spencer Jones, "Life on Other Worlds". The varied life such as we know it on the earth, is largely dependent on the ability of the carbon atom to combine into complex structures. This is possible only within a narrow range of temperature. Life must also have the support of an atmosphere. A survey of the other bodies of the solar system shows them for the most part to be lacking in one or other of the requirements of temperature and suitable atmosphere. Venus and Mars alone hold any possibility of life. While it is highly probable that Venus may be as our earth was millions of years ago, it seems just as probable that Mars represents the future state of the earth, namely, the sear and yellow leaf of old age.

A mathematical survey of the milky way indicates that the number of planetary systems such as our own, is small. Then the narrow limits that must be imposed upon any planet to give us life such as it is on the earth, makes the chance of finding such a planet very small indeed. When the investigation is extended to the vast reaches of the external galaxies, the chances become much greater. So while we may conclude that the earth may be unique in our own great milky way, it is quite likely to be duplicated many times over in the great universe of galaxies. Doubtless, wherever the conditions are favourable for life, life will develop.

M. M. THOMSON, *Secretary.*

The Royal Astronomical Society of Canada

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